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MICROWAVE CAVITY MEASUREMENT OF THE FARADAY EFFECT IN A MAGNETOPLASMA*

(M.A. Thesis)
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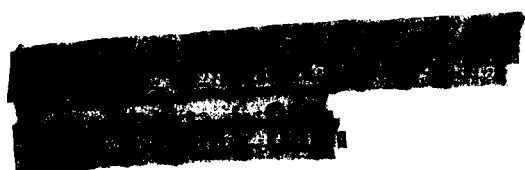
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ABSTRACT

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We have observed the coupling of the orthogonal, linearly polarized, TE_{111} modes of a right cylindrical cavity due to the Faraday Effect in a coaxially located neon glow discharge. Measurements as a function of applied magnetic field are interpreted in terms of a simple theory to yield an effective electron collision frequency. The values of the collision frequency obtained in this way are greater than predicted from the momentum-transfer collision cross-section. Some data showed anomalies near harmonics of electron cyclotron resonance, but these data were not reproducible.

But how



I. INTRODUCTION

Previous investigators (Rao and Goldstein, 1962) have considered the Faraday Effect for microwaves propagating in a plasma-filled waveguide; others (Buchsbaum, Mower, and Brown, 1960) have considered the effects of a plasma on the properties of the standing-wave modes in a cavity. To our knowledge, no experiments have been done on the Faraday Effect in a plasma contained in a cavity, although such experiments have been done in paramagnetic solids (Portis and Teaney, 1958), and semiconductors (Nishina, et al, 1961).

We shall first give an outline of the theory of the coupling of otherwise independent cavity modes due to the Faraday Effect, and then proceed to discuss our experiments and our results in terms of the theory. We find that, while the results resemble those predicted by the theory, the value of electron collision frequency which is required to fit the experimental curves is higher than one would expect from the known value of the momentum transfer collision cross-section for the gas used.

While it was hoped that this method would be capable of detecting harmonics of electron cyclotron resonance, our results to date have been inconclusive; harmonics seem to appear at times, but cannot be reproduced from day to day.

II. THEORY OF THE MODE COUPLING DUE TO FARADAY EFFECT

We consider a cavity in which the two degenerate TE_{111} modes are sufficiently removed from the other modes that the latter can be neglected in describing the electromagnetic field in the cavity. We also assume that the effect of a coaxially located plasma of radius small compared to that of the cavity may be treated as a perturbation to the degenerate modes. Considering the cavity shown in Figure 1, we assume that the cavity geometry has been arranged so that, in the absence of a magnetic field, there is no coupling between the input and the output probes.

Under these conditions, one may write the differential equations for the amplitudes of the two orthogonal TE_{111} modes after the manner of Slater (Slater, 1950). In the presence of a magnetic field, these modes are coupled because the current induced in the plasma by a given component of the electric field has a component perpendicular to the field component. The coupling is proportional to the off-diagonal component of the plasma conductivity tensor. In the integrals over the cavity volume which occur in the coupling term, furthermore, one can treat this component as constant over the plasma volume and zero outside, provided the plasma column is small enough so that the electric field is essentially constant in direction over a given cross-section.

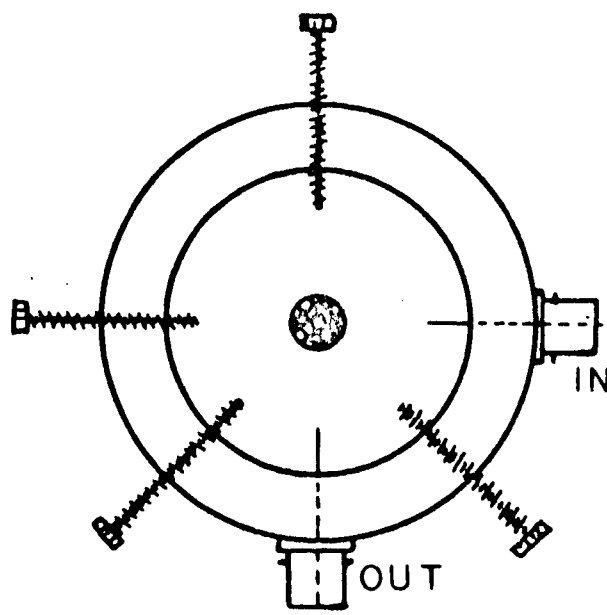
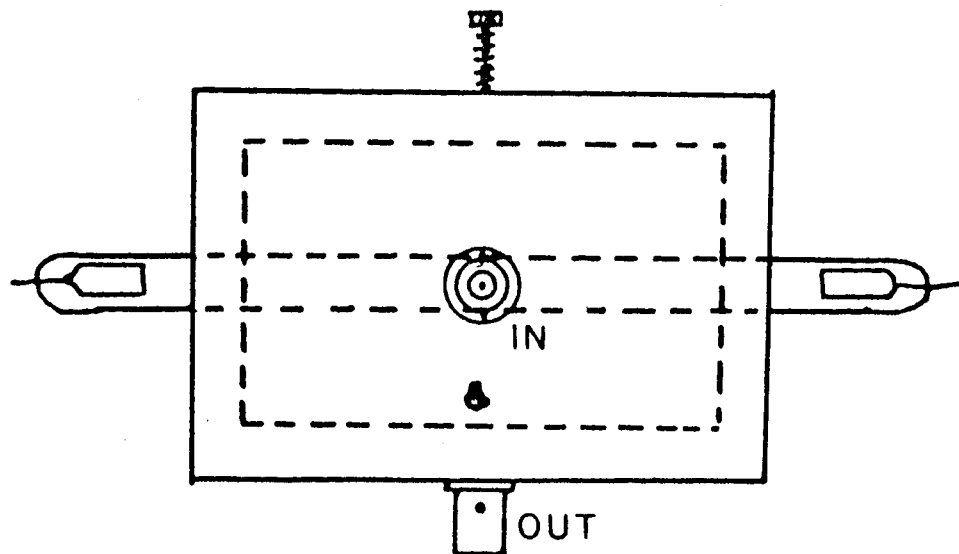


Figure 1. Diagram of microwave cavity.

Under the above assumptions, if one seeks the steady-state solutions of the equations when a sinusoidal driving force is applied to the first mode, one obtains a pair of algebraic equations for the mode amplitudes X_1 and X_2 of the form:

$$\begin{aligned} A_{11}X_1 + A_{12}X_2 &= F_1 \\ \text{and} \quad -A_{12}X_1 + A_{22}X_2 &= 0 \end{aligned} \quad (1)$$

where the A_{ij} are constants and F_1 is the amplitude of the driving signal. A_{12} is given by a geometrical factor times the off-diagonal component of the conductivity tensor, and the parameters of the second mode have been chosen to include those of the termination. We further note that the equations obtained by setting F_1 to 0 are those discussed by Buchsbaum, et al (Buchsbaum, Mower, and Brown, 1960), and that for a real (finite Q) cavity they have no solutions for real frequencies. This means that equation (1) may be solved to yield

$$X_2/F_1 = A_{12}/(A_{11}A_{22} + A_{12}^2) \quad (2)$$

We next simplify this expression by noting that the denominator of the right hand side is the secular determinant, D , which may be factored into $C(w^2 - w_1^2)(w^2 - w_2^2)$, where w is the (angular) signal frequency and w_1 and w_2 the natural frequencies of the two modes (which we have already noted are non-real). In our experiment we tune the cavity so that the real parts of w_1^2 and w_2^2 are equal to the signal frequency. Our cavity Q is relatively low, so it seems reasonable to assume that D has a relatively large contribution from the imaginary parts of w_1^2 and w_2^2 and that its magnitude is little affected by changing the applied magnetic field. (i.e., we assume that, for a low- Q cavity, D is a slowly varying function of the applied magnetic field).

We thus find that the ratio of input power (proportional to $/F_1/2$) and output power (proportional to $/X_2/2$) is given by

$$R = P_{out}/P_{in} = \text{Const. } /s_{12}/2 \quad (3)$$

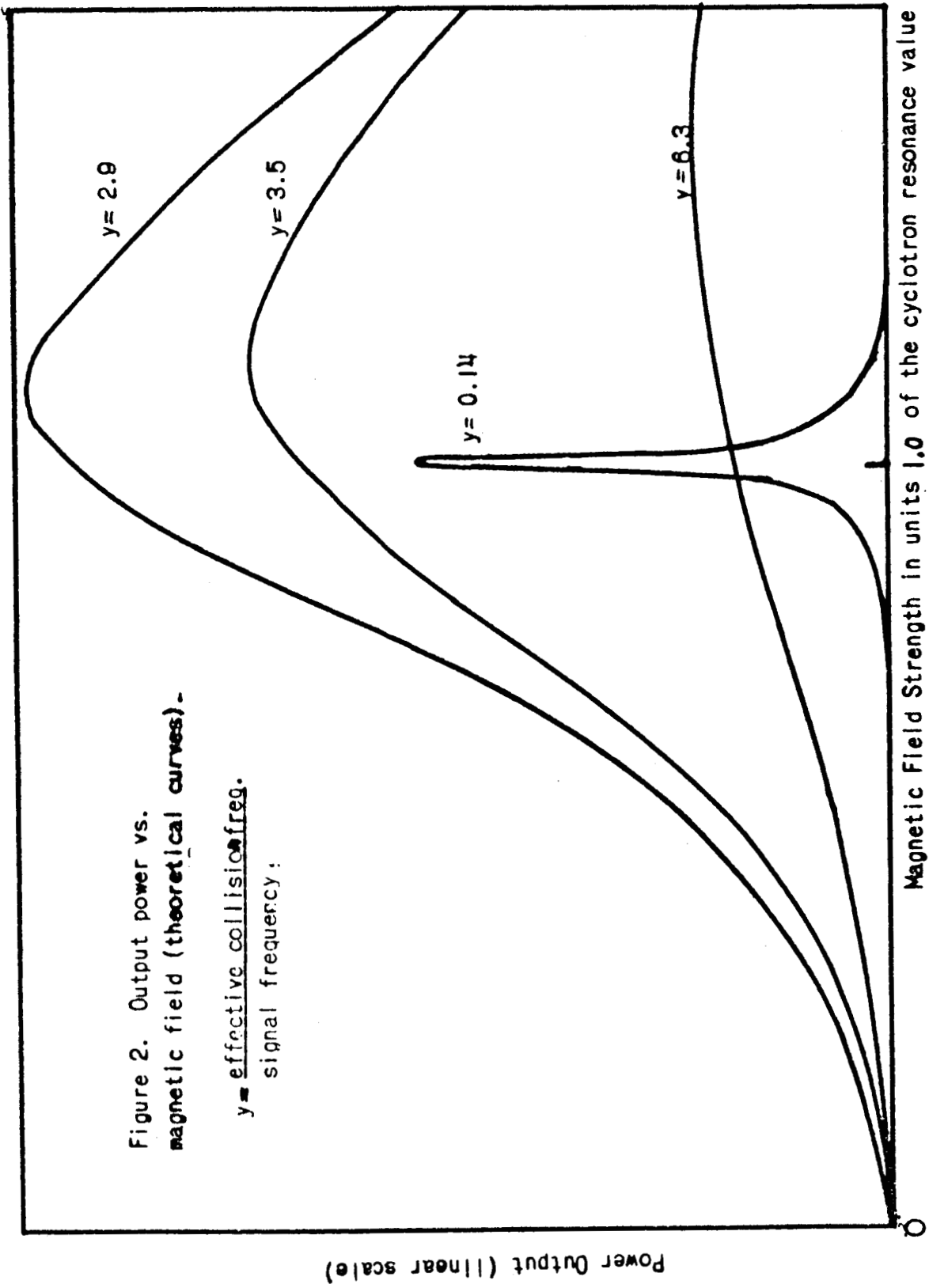
if s_{12} is the off-diagonal component of the conductivity tensor of the plasma. For a cold plasma, this component is given in terms of the plasma frequency w_p , the electron cyclotron frequency w_c , the collision frequency v_{eff} , and the signal frequency w by the expression:

$$s_{12} = \frac{iE_o w_p^2 w_c}{w_c^2 - (w - i v_{eff})^2} \quad (4)$$

We are interested in the dependence of this expression on the applied magnetic field, which is proportional to w_c . This dependence is shown for several values of v_{eff} in figure 2.

III. EXPERIMENTAL APPARATUS

Our apparatus consists of a cylindrical aluminum cavity, with input and output probes located perpendicular to each other in the mid-plane of the cavity. Opposite each probe is a tuning screw to adjust the corresponding mode to resonance with the signal frequency in the absence of an applied magnetic field. At 45° angles on either side of one probe are located two decoupling screws to allow one to adjust the cavity so that the two probes are not coupled in the absence of a magnetic field.

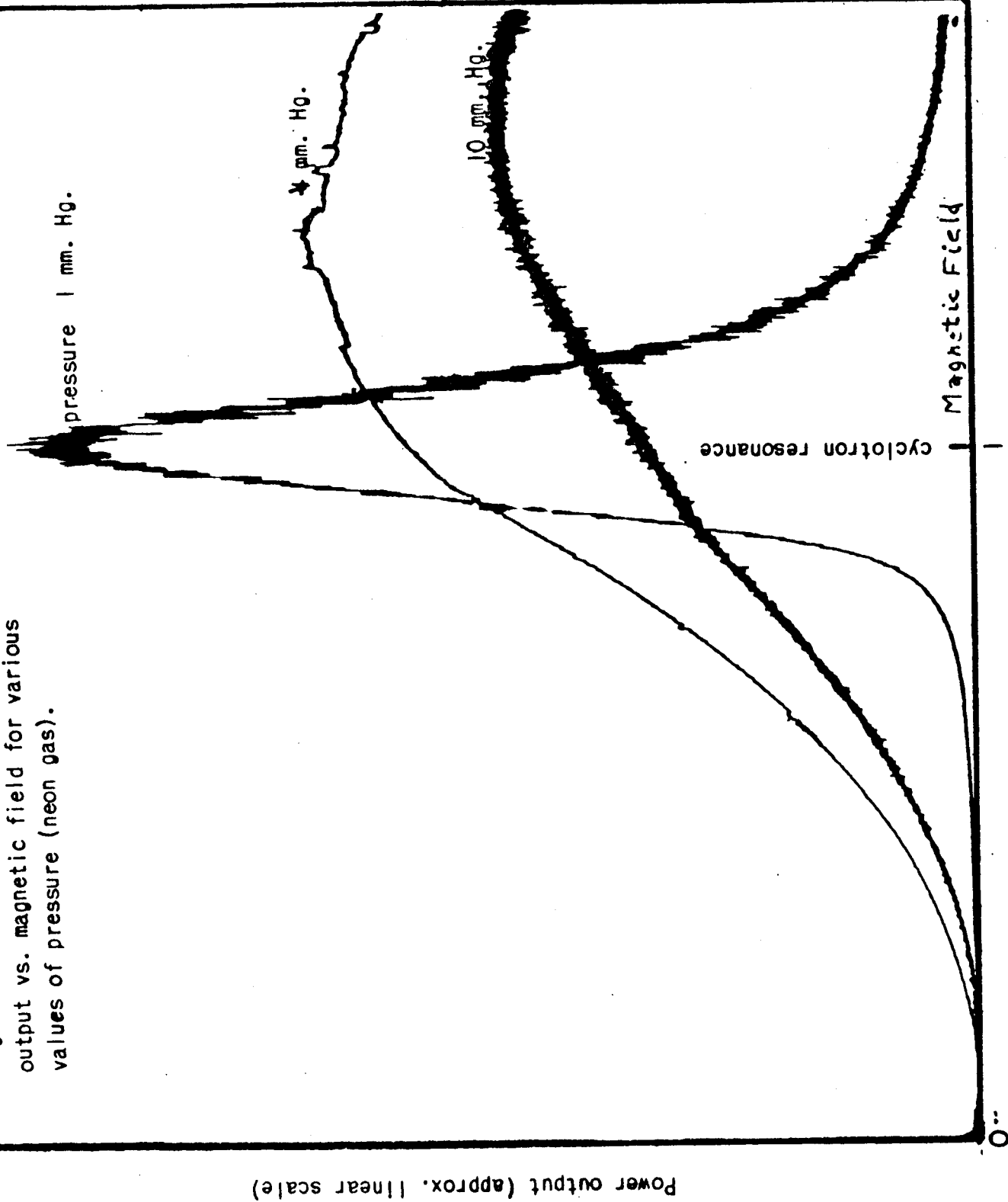


The plasma is produced by a glow discharge at currents of a few tens of milliamperes in a neon-filled discharge tube which passes through centrally located holes in ends of the cavity. A magnetic field is produced parallel to the axis of the cavity by a pair of coils of rectangular cross-section, arranged in a Helmholtz type configuration. The 2000 Mc. signal is supplied by a klystron signal generator, pulse modulated at 1000 cps. The output signal is measured by using a crystal detector and amplifying the resulting 1000 cps signal in a twin-T amplifier. The output of the amplifier is rectified and used to deflect an X-Y plotter in the Y-direction. The X-deflection is provided by the output of a Hall-effect gaussmeter which senses the magnetic field applied to the plasma.

IV. EXPERIMENTAL RESULTS

Typical data for several values of neon pressure are shown in figure 3. Curves run at different values of discharge current seem to agree well with the dependence of output power on electron density; the curves have approximately the same shape for different currents and the amplitudes are approximately proportional to the square of the current. Some difficulty was found in reproducing data, particularly in the low-pressure tube, since we used sealed-off tubes and their characteristics changed with operation. One may obtain the collision frequency, ν_{eff} from the graphs if one notes that the maximum output should occur at $\omega_c^2 = \omega^2 + \nu_{\text{eff}}^2$.

Figure 3. Recorder traces. Power output vs. magnetic field for various values of pressure (neon gas).



For the 4 mm. tube, this gives a value of v_{eff} of about 1760 Mc., as compared to a value of 700 Mc. from the momentum-transfer cross-section. An example of a "bumpy" curve which may show resonance at harmonics of cyclotron resonance is shown in figure 4. Data of this kind were fairly often obtained, but could not be repeated from one day to the next.

We have also observed that the apparent collision frequency obtained from our data seems to depend on the discharge current. We have not as yet investigated this effect to any appreciable extent, and cannot give any explanation of it at present. Finally, it will be noticed that the output signal becomes noisy for magnetic fields greater than that required for cyclotron resonance. We can at present only speculate whether or not these phenomena, and the large apparent collision frequency may be attributed to instabilities in the discharge. These matters are being investigated further.

V. CONCLUSIONS

We have found that observations of the coupling between the otherwise degenerate TE_{111} modes of a cylindrical cavity due to the Faraday Effect in a magnetoplasma agrees with the predictions of a simple theory. The results may easily be interpreted to yield an apparent collision frequency for the plasma electrons. The result is somewhat higher than would be predicted from the known cross-section for momentum transfer with neutrals.

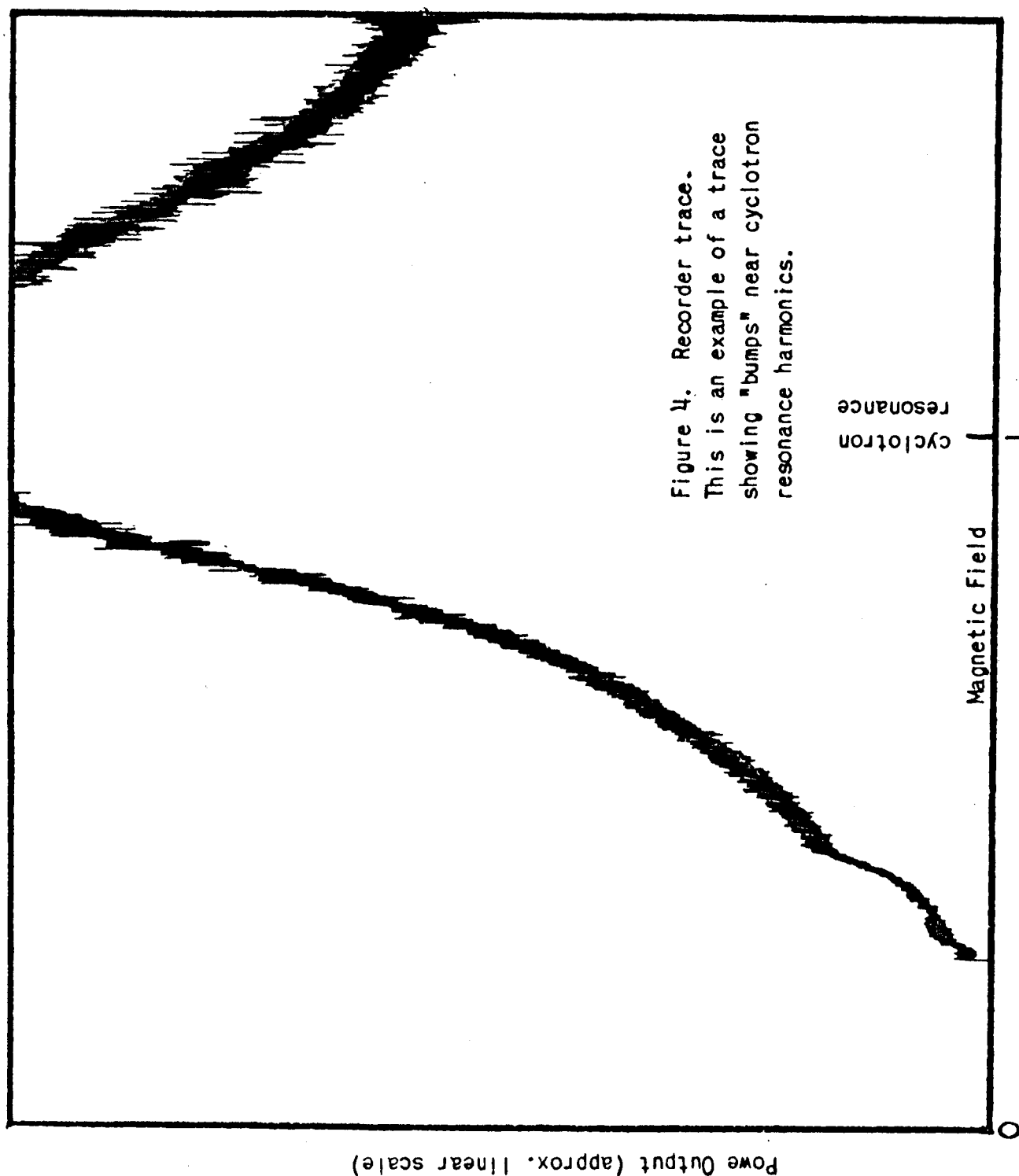


Figure 4. Recorder trace.
This is an example of a trace
showing "bumps" near cyclotron
resonance harmonics.

The investigations must be carried somewhat farther before we shall be able to explain this effect. While attempts to observe resonances at cyclotron frequency harmonics have yielded apparent success under some circumstances, we have not been able to reproduce these data consistently from day to day.

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